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A non-cooperative target grasping position prediction model for tethered space robot

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A B S T R A C T

How to identify proper grasping positions on non-cooperative targets is an essential technology for tethered space robots when implementing on-orbit service. To localize unknown targets, most template-based methods require a large set of well-engineered templates. Sliding them over the image to decide potential target positions is exhaustive and inefficient. To solve this rather complex problem, we propose a novel object localization method by predicting object regions before extracting them. It can reduce the search area of targets remarkably and runs fast. Firstly, the features of histogram of oriented gradients are modified to be more discriminative. Then the cascaded support vector machine is used to select better proposals over scales and aspect ratios. We also integrate the pre-processing procedure to highlight active target features. Further experiments demonstrate that our method improves the detection rate in VOC 2007 favorably and performs well in satellite brackets localization.

1. Introduction

On-orbit service technologies have a wide range of applications in the fields of on-orbit maintenance and space debris removal, where the manipulators equipped with grippers are usually used as the main actuator. Non-cooperative targets are usually malfunctioned satellites or space debris without artificial labels, grappling fixtures and information communications [1]. Due to the rigid body structures, manipulators tend to suffer limitations of manipulator length and flexibility in capturing non-cooperative targets.

To avoid potential collision, the tethered space robot (TSR) has been taken into consideration, which uses a space tether instead of the multi-freedom rigid manipulator and efficiently improves mission reliability. As a new type of robot system shown in Fig. 1 a), the architecture of TSR comprises a robot platform, space tether, and an operational robot. Herein, we focus on the short-tethered TSR system.

1.1. Mission description

The typical mission flow of providing an on-orbit service usually includes three sequential stages [2], which are described as follows.

(a) The robot platform searches the target and approaches it gradually from a far-range distance under the control of its own devices.
(b) TSR flies around the target and detects corresponding regions to identify a suitable position to release the operational robot. Then, the operational robot will be launched out and freely fly towards the frontal target [3]. Meanwhile, it keeps detecting the suitable grasping region of the target to guide end-effector in precise manipulation.
(c) The operational robot grasps the target once reaching the appointed position (usually less than 0.15 m) and eliminates the tumbling of the robot-target combination with its own propellants [4]. Then it provides on-orbit services, such as injecting propellants and dragging the target into a graveyard orbit. We give a schematic diagram of the TSR's task in Fig. 2.

In second phase, the operational robot needs to constantly measure its relative pose and attitude information to the grasping region of the target. Though microwave radar and laser radar have been used in relative navigation, we select charge-coupled device (CCD) cameras mounted on the operational robot to provide vision-based measurements due to their low mass and rich view information. In order to guide the entire approaching procedure from far-range distance to close-range distance, we design a vision system with four charge-coupled device (CCD) cameras in the faceplate. Two of them, C1 and C2 with 20 degree angular field of view (FOV), are used to detect far-range targets while the other

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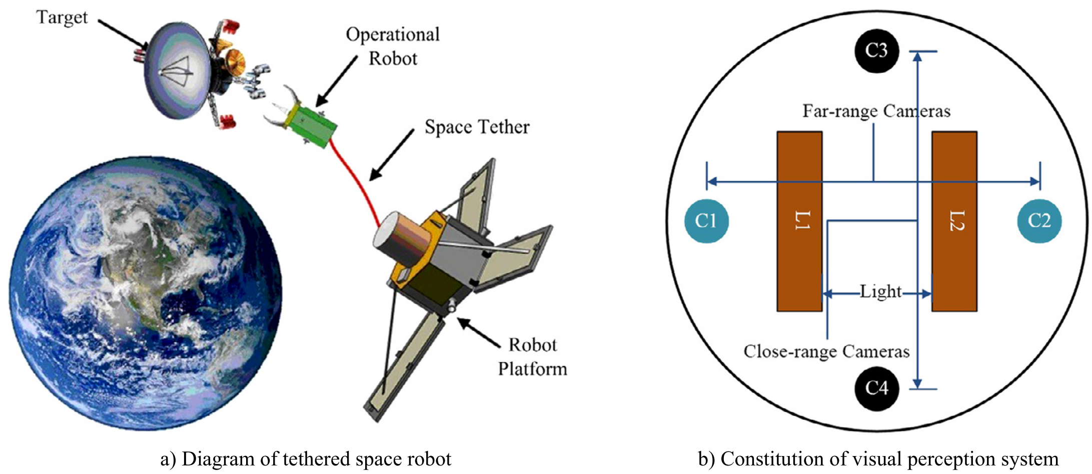

Fig. 1. Components of the TSR system and the camera layout in visual perception system.

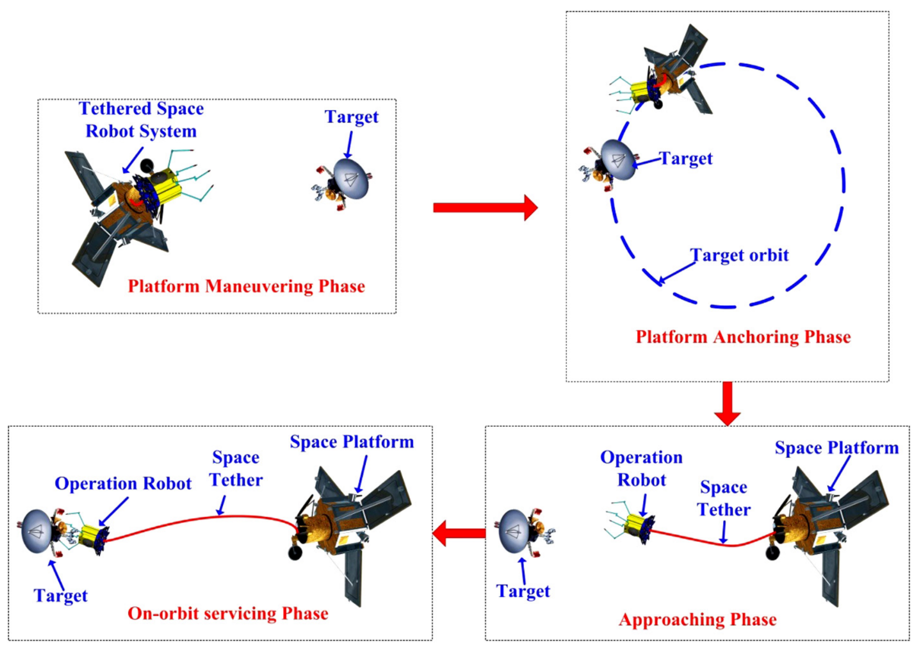

Fig. 2. Task flow of the TSR in providing on-orbit service.

two, C3 and C4 with 40 degree FOV angles, are for close-range targets, as shown in Fig. 1 b).

1.2. Grasping position selection

In order to select a proper grasping structure as our region of interest (ROI), we have investigated the main grasping positions of some existing projects, as shown in Fig. 3. They include the explosive bolt, apogee motor injector, docking ring and the satellite bracket.

The benefits of selecting them as the grasping positions are two-fold: First, they are generally the necessary equipment for a spacecraft and ensure the generalization of the grasping system. Second, they usually have geometric shapes, whose detection problem has been widely researched [5]. Hence, the simple but reliable geometric shape (straight line, triangle, circle, etc.) detection methods could be used. For the explosive bolt, it embeds one or more explosive charges and will be broken into pieces. To prevent possible damage to the spacecraft, it is commonly surrounded by a circle field. For the apogee motor injector, it has a cone-like shape and is connected at the end of the apogee engine. But the problem of these two structures is that they usually ask for a rather precise control and more concerns should be put on control algorithms instead of grasping position localization.

For the docking ring, it is the key mechanism of any docking system and also with cyclic shape. However, they are mainly used to deal with cases of cooperative targets. Grasping the docking ring will become much difficult if the target moves unstably.

For the satellite bracket, it is the connection between satellite main body and solar spans. Its shapes are limited to be geometric, such as pole, triangle and rectangle. Considering its wide existence in spacecraft and low control requirement, we select the satellite brackets as our grasping region.

1.3. Related works

Providing on-orbit servicing can be divided into several phases (as shown in Fig. 2) and involves many key techniques. In platform anchoring phase, the detection, pose estimation and tracking of the target spacecraft are quite important in order to select a secure and applicable approaching path. The 3D points by stereo vision [6] and 3D target model [7,8] are commonly used to achieve this.